ELEC 361: Quantum Mechanics for Engineers

Junichiro Kono

Spring 2022

Time and Place

Time: 2:30 pm – 3:45 pm CT, Tuesdays & Thursdays
Place: Herman Brown Hall 453

Contact Information

Instructor: Junichiro Kono
Office: 351 Brockman Hall
Email: kono@rice.edu
Office Hours: 10:00 AM – noon CT, Wednesdays (via Zoom)

Teaching Assistants: Dasom Kim (kdsgod@rice.edu) and Elijah Kritzell (tek3@rice.edu)
Technology TA: TBA

Course Objectives and Learning Outcomes

This course provides engineering undergraduate students with the physical understanding and mathematical prowess necessary for designing quantum devices and systems, including quantum computers. The main players are thus electrons in solids throughout. The students are expected to learn: 1) when, or under what conditions, quantum effects become nonnegligible in devices, 2) how to calculate the quantum states (wave functions) and energies of electrons moving in artificial potential structures, and 3) what determines the electrical and optical properties of quantum solid-state devices. The essential mathematical foundations of quantum mechanics will be introduced as early as possible and then immediately followed by quantum information and quantum computing, which is one of the most significant emerging applications of quantum mechanics. We will aim to strike a good balance between rigorous mathematical derivations and example problem solving. The problems will be practical, including such modern topics as quantum-well infrared photodetectors, solar cells, quantum teleportation, Bloch oscillations, band gap engineering for LEDs, quantum cascade lasers, topological band structure, and band diagrams of van der Waals heterostructures.

Texts and Materials

J. Kono, *Quantum Mechanics for Tomorrow's Engineers* (Cambridge University Press)

In addition, the following texts are recommended:

- *Applied Quantum Mechanics* by A. F. J. Levi (Cambridge, 2006).
- *Modern Quantum Mechanics* by J. J. Sakurai (Addison-Wesley, 1994).
- *Quantum Mechanics: Fundamentals & Applications to Technology* by J. Singh (John Wiley & Sons, 1999).
- *The Meaning of Quantum Theory* by J. Baggott (Oxford University Press, 1992).
- *Quantum Mechanics: For Engineering, Materials Science and Applied Physics* by H. Kroemer (Prentice Hall, 1994).
- *An Introduction to Theory and Applications of Quantum Mechanics* by A. Yariv (John Wiley & Sons, 1982).
- *Quantum Mechanics* by D. K. Ferry (Institute of Physics, 2001).
- *Quantum Physics* by S. Gasiorowicz (Wiley, 1995)
- *Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles* by R. Eisberg and R. Resnick (Wiley, 1985)

Homework

A problem set will be assigned every week. Late homework assignments will be accepted with a penalty of 10% per class period after they are due.

Exams

There will be two exams: Midterm and Final Exams. The Midterm will be an in-class exam, whereas the Final will be a take-home exam. Both are open-book exams.

Grading

Homework 50%; Midterm Exam 25%; Final Exam 25%.

Office Hours

Office hours, either in person or online, are by appointment only. Email the instructor to set up an appointment.

PPE & Physical Distancing

- Every student in the classroom is expected to properly wear a mask or face covering and to abide by Rice's physical distancing policy (maintain at least six feet of distance from other persons whenever possible).
- The instructor reserves the right to instruct students to leave the classroom if they are engaging in behavior that places faculty and/or students' health at risk. If students do not comply, the instructor may cancel the class meeting and refer the student to Student Judicial Programs and the Dean of Undergraduates or the Dean of Graduate and Postdoctoral Studies.

Privacy and Confidentiality

In line with FERPA requirements, recorded classroom discussions involving students will be available only to students officially registered and enrolled in the class. If you have concerns about appearing on these recordings, please contact the instructor ahead of time.

Rice Honor Code

In this course, all students will be held to the standards of the Rice Honor Code, a code that you pledged to honor when you matriculated at this institution. If you are unfamiliar with the details of this code and how it is administered, you should consult the Honor System Handbook at http://honor.rice.edu/honor-system-handbook/. This handbook outlines the University's expectations for the integrity of your academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process.

Disability Resource Center

If you have a documented disability or other condition that may affect academic performance you should: 1) make sure this documentation is on file with the Disability Resource Center (Allen Center, Room 111 / adarice@rice.edu / x5841) to determine the accommodations you need; and 2) talk with me to discuss your accommodation needs.

Syllabus Change Policy

This syllabus is only a guide for the course and is subject to change with advanced notice.

Course Schedule

1. **Quantum-Enabled Technologies**

   Understand the limit of miniaturization of electronic devices and the need for genuinely quantum devices. Become familiar with some of the key emerging concepts, materials, and devices to go beyond the traditional silicon based technologies. Get a glimpse of the currently occurring second quantum revolution, especially the advent of quantum information processing.

2. **Electronic Waves and Schrödinger's Equation**

   Develop an understanding of when and how classical particles start behaving as quantum mechanical waves. Derive the most fundamental equation in quantum mechanics, the Schrödinger equation, which determines the states and dynamics of quantum particles. Solve the Schrödinger equation for example problems for electrons in simple potential energy landscapes.

3. **Mathematical and Conceptual Foundations**

   Become proficient in operator algebra. Understand the simple harmonic oscillator problem using operators. Develop a grasp of quantum notions such as observables, Hilbert space, superposition, and wavefunction collapse. Become fully conversant with Dirac notation. Learn the matrix formulation of quantum mechanics.

4. **Quantum Information Processing**

   Understand the basic concepts of qubits and the Bloch sphere. Appreciate the meaning and implications of quantum entanglement. Become able to perform quantum gate operations to control qubits using unitary matrices. Become familiar with quantum circuits.

5. **Electron Motion in Potential Landscapes**

   Learn how to use unbound states in analyzing particle dynamics. Understand the phenomenon of quantum tunneling. Apply the propagation matrix method to study various 1D potential problems. Become familiar with the basic concepts of the band theory of solids.

6. **Light-Matter Interaction**

   Become familiar with the time-dependent Schrödinger equation. Learn the basic ideas of perturbation theory. Become able to calculate transition probabilities using Fermi's golden rule. Derive the optical Bloch equations using the density matrix formalism. Understand the concepts of population inversion, gain, and lasing using rate equations.